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A planar hybrid transceiving mixer at 76.5 GHz for automotive radar applications

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Abstract. A growing number of applications for radar systems in automobiles demands for low-cost radar front-ends. A planar monostatic radar front-end is particularly suited for low cost applications as it uses only one antenna for transmission and reception and, thus, minimizes the needed chip area.

Generally, in a standard homodyne radar a radio-frequency (RF) signal generated by an oscillator is used for both, the transmitted signal and the local oscillator (LO). Well controlled distribution of the input power between antenna and mixer is crucial. A transceiving mixer at 76.5 GHz is presented, where this distribution is done by use of a rat-race coupler. In a conventional transceiver the oscillator signal is split into the transmitted and in the LO signal by a directional coupler. A second directional coupler is needed in order to merge the received and the LO signal at the mixer. In our design the purpose of splitting and merging the signals is realized with only one coupler. Elimination of the second coupler reduces losses significantly.

The received signal is down-converted to the intermediate frequency (IF) by use of a balanced mixer. For small relative speed in a CW-Doppler-radar or short distance in a FMCW-radar the IF is very small. Therefore 1/f noise is a significant value. In order to achieve good 1/f noise characteristics, Schottky diodes were used. The diodes were flip-chip bonded onto a microstrip circuit on a Al_2O_3 substrate.

The assembled transceiver was measured on-waver. An input power of 7 dBm was applied. The measured output power was 3 dBm and the conversion loss 9 dB. A noise figure of 15.3 dB was measured at 100 kHz.

1 Introduction

The demand for radar applications in the automotive sector is rapidly growing. Such applications are, e.g. distance measurement for the automotive cruise control, parking aid, side crash detectors or blind spot detection. Combining all the intended applications the car will be included in a radar bubble. The applications will support the driver and increase the road safety. First radar systems are already on the market. By now they are only implemented in upper class cars. However, in order to extend the applications and to open up the mass market for these systems, additional research work is still required and is already on it's way to be done (Dixit, 1997). For the mass market costs, reliability and easy fabrication are the most important factors. These needs can be satisfied best with hybrid or monolithically integrated circuits (Meinel, 1995).

By now no single chip implementation for the radar front-end exists or makes economic sense, and therefore the hybrid assembly offers some advantages. It is easy to combine different types of semiconductors like GaAs and silicon. Furthermore these active semiconductor devices can be mounted onto a cheaper substrate with the printed structures of the passive elements. Even more there is flexibility for the antenna design. The objective of the herein presented design was to reduce costs and losses by reducing the elements and the required substrate area. This is especially an advantage for MMIC circuits, but also for the less costly hybrid assembly reducing the size is a design goal.

2 Concept

In a traditional transceiver the oscillator signal is divided in the transmitted and in the LO signal by a directional coupler. In addition a second directional coupler is needed in order to merge the received and the LO signal at the non-linear devices of the mixer. In such a concept losses are considerable due to large structures. In this design the purpose of splitting and merging the signals is realized with only one directional coupler. A planar monostatic radar front-end is particularly suited for low-cost application as it uses only one antenna for transmission and reception and, thus, min-

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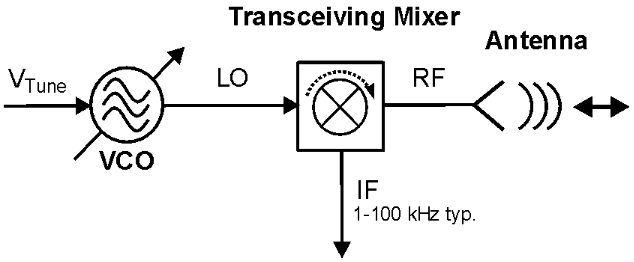

Fig. 1. Block diagram of a homodyne radar front-end.

imizes the needed chip area. For small relative speed in a CW-Doppler-radar or short distance in a FMCW-radar the IF is very small. Therefore 1/f-noise is a significant value. In order to achieve good 1/f-noise characteristics, silicon Schottky barrier diodes were used. Compared to GaAs based diodes they provide a lower 1/f-noise cut-off frequency. The diodes were flip-chip bonded onto a microstrip circuit on a Al_2O_3 substrate with microstrip waveguide structures. The flip-chip assembly using thermal compression bonding is suited for fully automated fabrication.

The largest noise contribution in a transceiving mixer is the LO AM noise. In order to gain good AM noise suppression at the IF port, a singly balanced mixer was used as the down-converting device. Thereby the signal is applied in phase to the diodes of the balanced mixer whereas the AM LO noise is applied out of phase to the diodes and therefore is rejected. The use of the singly balanced mixer principle is a good tradeoff between low losses and sufficiently high AM noise suppression. The singly balanced mixer can be realized by use of a 90° or a 180° hybrid. The designs basically differ in RF-LO isolation, but not in noise suppression. (Maas, 1993) The block-diagram of a homodyne radar front-end is illustrated in Fig. 1. This work deals with the transceiving mixer. The purposes of transmitting a part of the signal power to the antenna, driving the diodes and the mixing are all included in this element. The goal of the presented design was to realize these functioning with a minimum of components. Within this reduction the components usually allocated to a single function are merged into a single component. Therefore, in the resulting element, there is no more clear allocation between a special function and a discrete element.

Generally, in a standard homodyne radar a radio-frequency signal generated by an oscillator is used for both, the transmitted signal and the local oscillator. Well controlled distribution of the input power between antenna and mixer is crucial. There is a tradeoff between the output power, i.e. the fraction of power, which is transmitted, and the LO power level at the diodes determining the conversion loss of the mixer. Both parameters influence the achievable range of the radar.

The microstrip circuit was designed based on a full wave analysis. The whole front-end was simulated using a harmonic-balance method.

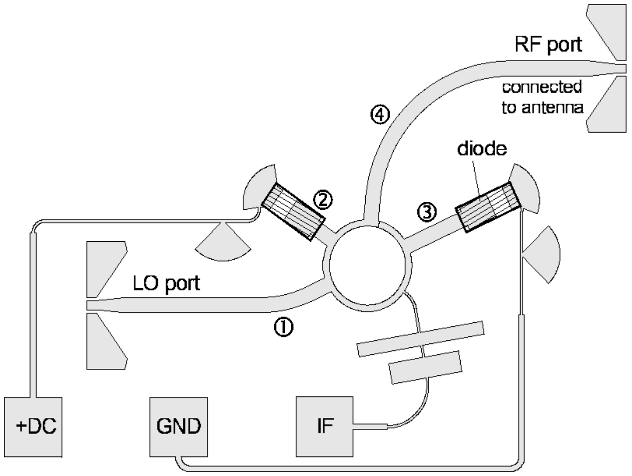

Fig. 2. Complete transceiving mixer layout.

3 Realization

In a hybrid, the power from the input port (1) is equally delivered to two output ports (2,3). A fourth port (4) is isolated from the input port. At port (4) the antenna will be attached. The diodes are attached to ports (2,3). The concept of this transceiver is based on the bypass of the isolation between port (1) and port (4). This is achieved by the mismatch of the diodes at ports (2,3). Therefore the oscillator applied to port (1) feeds the diodes at ports (2,3) with LO power and in addition a fraction of it's power is transmitted to port (4) via the reflections on the mismatched diodes (Siweris, 1997).

The realization of a 90° hybrid is difficult due to the requirement of very low impedance lines. In contrast a 180° rat-race hybrid is simple to design and is transferred into a 90° hybrid by inserting a $\lambda/4$ long microstrip line between the rat-race and one of the diodes. Therewith the reflected signals are superimposed in phase at the antenna port (Grübl et al., 2002). The complete transceiving mixer layout with an indication of the diodes position is shown in Fig. 2.

The diodes are grounded by a virtual short realized with a radial stub. Since the properties of the diodes were not completely known, due to the absence of an appropriate model, the position of the virtual short was determined experimentally.

The IF is applied at the rat-race ring. The detachment of the IF from the RF matched part should not influence the symmetrical power distribution and, therefore, the AM noise suppression. A very low symmetry distortion was achieved by applying a standard RF block with a low-pass filter consisting of two stubs in a certain angle to the rat-race ring. The singly balanced mixer principle allows to serially bias the diodes. The DC-bias part is isolated from the RF by use of standard bandstop structures using radial stubs. For the measurement with a waver-prober, coplanar-to-microstrip transitions were included at the LO and the RF port.

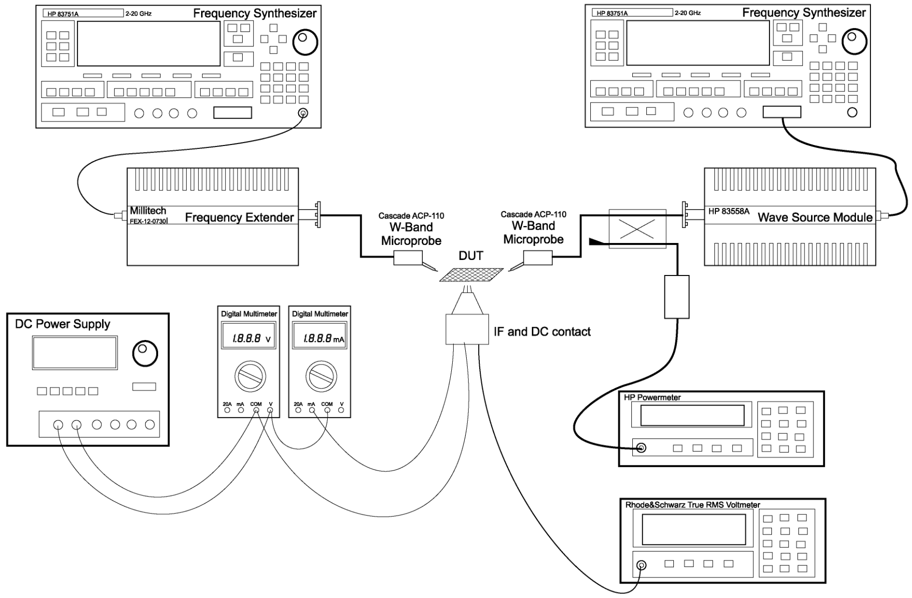

Fig. 3. Scheme of the measurement setup.

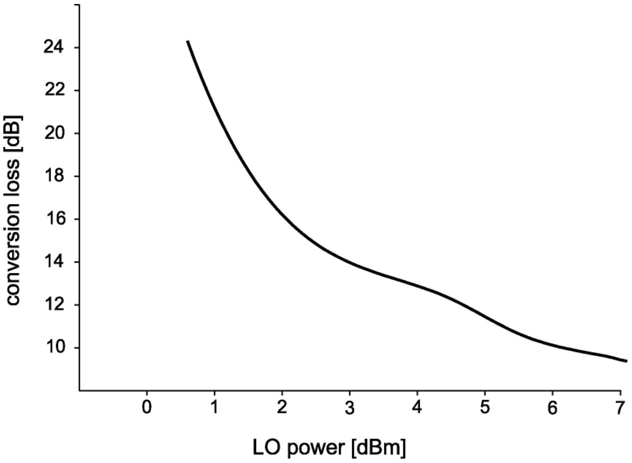

Fig. 4. Conversion loss vs. LO power.

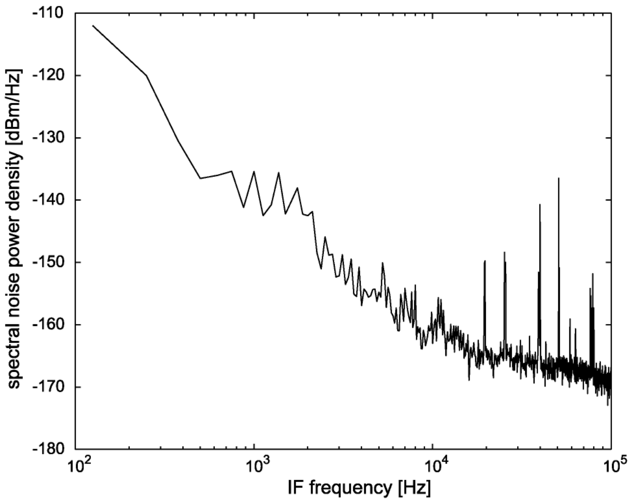

Fig. 5. Spectral noise power of the mixer.

4 Measurement

The assembled transceiver was measured on-waver with the setup illustrated in Fig. 3. To verify the simulation the passive circuit was first measured separately. In the following the complete mixer was measured with variations of the diode match and the virtual short. The measurement frequency was 76.5 GHz with an LO-power level of 7.1 dBm. The IF was measured with a True RMS Voltmeter. The optimum load impedance was determined to be 39Ω.

The frequency shift of the applied RF signal compared to the LO frequency was 100 kHz with a RF power of −20 dBm. The bias voltage of the diodes was adjusted separately for each mixer under test. It depended on the match of the diodes and the resulting drive of the diodes by the LO. For both diodes in series the applied voltage was about 400 mV.

The conversion loss was calculated from the measured IF voltage and the impedance of the load. The best results were shown by a mixer without any matching network at the diodes. It's minimum conversion loss was 8.9 dB. Figure 4 shows the obtained results.

The noise figure of the mixer was characterized also. In order to measure the 1/f-noise the IF signal was amplified by use of a low noise amplifier and measured using an spectrum analyzer. Only LO signal and DC bias voltage were applied to the mixer. The RF port was terminated using a 50Ω match. The measured noise power density is given in Fig. 5. The noise figure at 100 kHz was 15.3 dB. Herein the noise generated by the voltage source and the LO noise are included.

5 Conclusion

The presented transceiving mixer at 76.5 GHz takes advantage of the elimination of a second hybrid. Thus, losses and the required substrate area are reduced significantly compared to existing realizations. The LO-RF port isolation of the hybrid is bypassed via the reflections at the diodes of the singly balanced mixer. A matching of the diodes was found to decrease the performance, because of the additional losses. The measurements show low conversion loss of 8.9 dB at 3 dBm input power and excellent AM noise suppression.

References

Dixit, R.: Radar requirements and architecture trades for automotive applications, 1997 IEEE MTT-S Int. Micro-wave Symp. Dig., 3, 1253–1256, 1997.

Grübl, A., Herb, A. J., Raßhofer, R.H., Biebl, E.M.: A 76.5 GHz Transceiving Mixer Using Flip-Chip Mounted Silicon Schottky-Diodes for Automotive Radar Applications, EuMC Proceedings, 2002.

Maas, S. A.: Microwave Mixers, 2nd ed. Norwood, MA: Artech House, 1993.

Meinel, H. H.: Commercial Applications of Millimeterwaves History, Present Status, and Future Trends, IEEE Trans. Microwave Theory and Tech., MTT-43. 7, 1639–1653, 1995.

Siweris, H.-J.: Homodynes monostatisches Radarsystem, Patentschrift DE 196 10 850 C1, 1997.